ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Physics Procedia 27 (2012) 160 – 163
Physics Procedia

ISS2011

Fracture strength properties of Gd-Ba-Cu-O large single-grain bulk with CeO_2 addition

Akira Murakami[a], Hiroyuki Fujimoto[b], Akifumi Iwamoto[a,c*]

[a]Department of Mechanical Engineering, Ichinoseki National College of Technology, Takanashi, Hagisho, Ichinoseki 021-8511, Japan
[b]Railway Technical Research Institute, 2-8-38 Hikari-cho Kokubunji,Tokyo 185-8540, Japan
[c]National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan

Abstract

Fracture strength and Young's modulus in a $GdBa_2Cu_3O_y$ based large single-grain bulk were evaluated through three- and four-point bending tests of specimens cut from the bulk. The diameter of the bulk was about 150 mm. The bulk was fabricated in air. Scatter of the bending strength data in the bulk was mainly attributable to dispersion of pores. There was no significant difference in the bending strength value among the bending test specimens cut from inner region of the bulk. The bending strength of the large single-grain bulk was comparable to that of a smaller $GdBa_2Cu_3O_y$ bulk.

Keywords: $GdBa_2Cu_3O_y$; Single-grain bulk; Bending strength;Young's modulus; Porosity; CeO_2 addition

1. Introduction

Evaluations of fracture strength properties of $REBa_2Cu_3O_y$ (RE123, where RE denotes rare-earth elements) superconducting bulks are important for practical application because the superconducting bulks are subjected to electromagnetic force and thermal stress in the superconducting devices. It has been reported that Gd123 single-grain bulks have excellent superconducting properties [1,2]. It has been also reported that Gd123 based large single-grain bulks 140 mm in diameter could be fabricated without serious weak links [3,4]. However, fracture strength properties in such large single-grain bulks have not been understood. In the present study, fracture strength and Young's modulus in a Gd123 based large single-grain bulk 150 mm in diameter were evaluated through three- and four-point bending tests of specimens cut from the bulk.

2. Experimental Procedure

A Gd123 based large single-grain bulk sample fabricated by Nippon Steel Corporation was tested. Diameter of the bulk sample was about 150 mm. The bulk was fabricated in air. 10 wt.% Ag was added to the bulk. It is well-known that Ag addition is effective in improving the fracture strength properties of RE123 bulks. 1 wt.% CeO_2 was also added to the bulk to disperse fine secondary phase particles into the superconducting matrix, which is indispensable

* Corresponding author. Tel.: +81-191-24-4734 ; fax: +81-191-24-4734 .
E-mail address: amura@ichinoseki.ac.jp .

1875-3892 © 2012 Published by Elsevier B.V. Selection and/or peer-review under responsibility of ISS Program Committee
Open access under CC BY-NC-ND license. doi:10.1016/j.phpro.2012.03.435

for excellent superconducting properties. Details of fabrication processes for Gd123 based large single-grain bulk are reported in Ref. [5].

Bending test specimens with the dimensions of 2.8 x 2.1 x 24 mm^3 were cut from the bulk such that the 2.1 mm direction of the specimens almost corresponded to the *c*-axis of the bulk. Three- and four-point bending loads were applied at room temperature in the 2.1 mm direction of the specimens by means of INSTRON 4464 testing machine equipped with a 2 kN load cell. Crosshead speed was 0.1 mm/min. Three-point bending stress σ_3 and four-point bending stress σ_4 were calculated by using Eqs. (1) and (2), respectively.

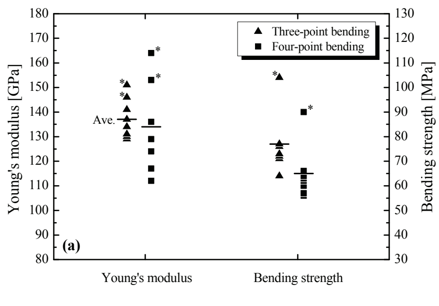
$$\sigma_3 = \frac{3PL}{2wt^2} \qquad (1)$$

$$\sigma_4 = \frac{3P(L-l)}{2wt^2} \qquad (2)$$

where P is applied load, L is outer supporting span (21 mm), l is upper loading span (7 mm), w and t are width and thickness of the specimens (2.8 mm and 2.1 mm). Strain by loading was measured through a strain gage glued to the center of the tensile side surface of the specimens. Strain gage length was 0.2 mm. After the bending tests, side surfaces of the fractured specimens were polished by using lapping sheets. Pores and secondary phase particles on the polished surfaces were observed by using a digital microscope.

3. Results and Discussion

Fig. 1 (a) shows Young's modulus and bending strength were evaluated through the three- and four-point bending tests of specimens. The Young's modulus values were obtained from a linear part of stress-strain curves. The four-point bending strength was lower than the three-point bending strength, which is due to the larger effective volume in the four-point bending test specimens. Although the Young's modulus is inherent in the material. The Young's modulus evaluated by the four-point bending tests was slightly lower than that by the three-point bending tests. It is deduced that one of the reasons for it is that specimens were easily deformed by the four-point bending loading due to some defect such as pores and micro-cracks contained in the larger effective volume region. Data points with asterisks in the figure were obtained for specimens cut from region near the top surface of the bulk. Both the Young's modulus and the bending strength of these specimens were higher than those of specimens cut from inner region of the bulk. The reason for it is mentioned in the followings. It has been reported that the average value of four-point bending strength data of specimens cut from a Gd123 bulk 46 mm in diameter was 58 MPa [6]. That bulk was fabricated from a Pt added precursor in air [6]. Pt addition was also conducted to disperse fine secondary phase particles into the superconducting matrix. Although, the dimensions of specimens in Ref. [6] and those in the present study are different from each other, the four-point bending strength values obtained in the present study were comparable to the average four-point bending strength value of the Pt added Gd123 bulk reported in Ref. [6].



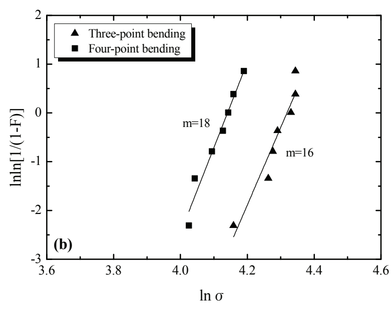


Fig. 1. Mechanical property data obtained through three- and four-point bending tests of specimens cut from bulk sample. (a) Young's modulus and bending strength. (b) Weibull plots of bending strength data. Data points with asterisks in (a) were obtained for specimens cut from region near the top surface of the bulk. Weibull plots were conducted excluding the data points with asterisks.

Fig. 1 (b) shows Weibull plots of bending strength data excluding the data points with asterisks in Fig.1 (a). Weibull coefficient value is commonly used to evaluate scatter of fracture strength data; larger Weibull coefficient value means smaller scatter of fracture strength data. Weibull coefficient value of the three-point bending strength data and that of the four-point bending strength data were 16 and 18, respectively, which were close to each other. These Weibull coefficient values were also close to the value of three-point bending strength data of a Dy123 bulk 30 mm in diameter reported in Ref. [7].

Fig. 2 shows polished side surfaces of bending tests specimens. Fig. 2 (a) is a surface of a specimen cut from region near the top surface of the bulk. Fig. 2 (b) is a surface of a specimen cut from inner region of the bulk. While pores are observed for the specimen cut from inner region of the bulk, few pores are observed for the specimen cut from region near the top surface of the bulk. One of the reasons for the extraordinarily low porosity is that inert gases are easily released near the surface of the bulk [8]. Porosities of the bending test specimens were evaluated through image analysis.

Fig. 3 (a) shows relationship between the Young's moduli evaluated through three- and four-point bending tests and the porosity. Fig. 3 (b) shows relationship between the three- and four-point bending strengths and the porosity. Relationship between the Young's modulus and the porosity of ceramic materials have been suggested in Ref. [9]. Relationship between the fracture strength and the porosity has been also suggested [10]. Data points in Fig. 3 (a) and (b) were approximated by using the equations suggested in Refs. [9,10]. Increase of the Young's moduli and the bending strengths with decrease of the porosity are observed. Such increases are mainly due to the increase of the net-cross sectional area with decrease of the porosity and to the decrease of the number of defects where the stress concentration occurs.

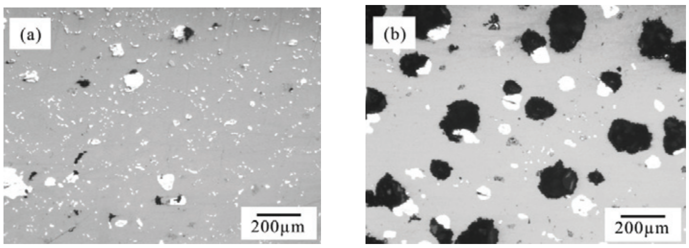


Fig. 2. Polished surfaces of bending test specimens. Black and white parts are pores and Ag particles, respectively. (a) Specimen cut from region near the top surface of the bulk. (b) Specimen cut from inner region of the bulk.

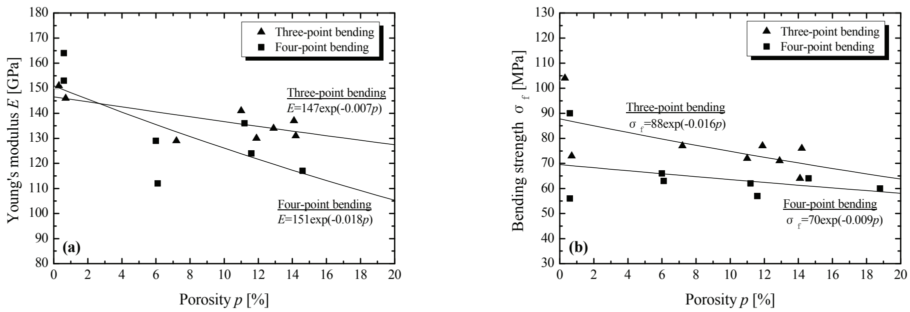


Fig. 3. Relationships between mechanical properties and porosity of three- and four-point bending test specimens. (a) Young's modulus. (b) Bending strength.

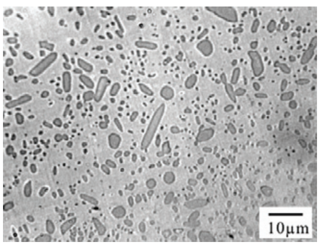


Fig. 4. Magnified view of polished surface of bending test specimen. Secondary phase particles are observed.

Fig. 4 shows magnified view of polished surface of a specimen. Needle-shaped secondary phase particles and spherical-shaped fine secondary phase particles are observed. The shapes and the sizes of the secondary phase particles were observed for the CeO_2 added bulk in the present study are similar to those of Pt added superconducting bulks reported in Ref. [11].

4. Conclusion

Bending strength and Young's modulus of Gd123 based large single-grain bulk 150 mm in diameter were evaluated through three- and four-point bending tests of specimens cut from the bulk. The bulk was fabricated in air. CeO_2 was added to the bulk to disperse fine secondary phase particles into the superconducting matrix. Bending strength values of the large single-grain bulk were comparable to the average bending strength value of a Pt added Gd123 bulk 46 mm in diameter. Both, the Young's modulus and the bending strength of low porosity specimens cut from region near the top surface of the bulk were higher than those of specimens cut from inner region of the bulk. Secondary phase particles of the CeO_2 added bulk was observed in the present study were similar to those of Pt added superconducting bulks.

Acknowledgements

We appreciate helpful assistance in the sample preparation by Dr. H. Teshima and Dr. M. Morita of Nippon Steel Corporation and experimental supports by students of Ichinoseki National College of Technology. This work was supported in part by the NIFS Collaboration Research Program (NIFS11KECA005).

References

[1] S. Nariki, H. Hinai, N. Sakai, M. Murakami, M. Otsuka. Effect of microstructure on the superconducting properties of Gd-Ba-Cu-O bulk fabricated in air. *Physica C* 2001; 357-360: pp.817-820.

[2] S. Nariki, H. Hinai, N. Sakai, M. Murakami, M. Otsuka. Trapped magnetic field of Gd-Ba-Cu-O/Ag bulk fabricated in air. *Physica C* 2002; 378-381: pp.764-768.

[3] N. Sakai, M. Kita, S. Nariki, M. Muralidhar, K. Inoue, I. Hirabayashi, M. Murakami. Field trapping property of Gd-Ba-Cu-O bulk superconductor 140 mm in diameter. *Physica C* 2006; 445-448: pp.339-342.

[4] N. Sakai, S. Nariki, K. Nagashima, M. Miryala, M. Murakami, I. Hirabayashi. Magnetic properties of melt-processed large single domain Gd-Ba-Cu-O bulk superconductor 140 mm in diameter. *Physica C* 2007; 460-462: pp.305-309.

[5] M. Morita, H. Teshima, H. HIrano. Development of oxyde superconductors –High-T_c bulk superconductor, QMG, and its applications-. *Nippon Steel Tech,Rep.* 2006; 93: pp.18-23.

[6] H. Fujimoto. Preparation and mechanical properties of large single domain GdBaCuO superconductor with low void density. *IEEE Trans Appl Supercond* 2009; 19: pp.2933-2936.

[7] A. Murakami, K. Otaka, T. Miura, A. Iwamoto. Mechanical properties of Dy123 low porosity bulk superconductors at liquid nitrogen temperature. *IEEE Trans Appl Supercond* 2011; 21: pp.3107-3110.

[8] H. Tanaka, S. Nariki, N. Sakai, I. Hirabayashi, M. Murakami, T. Takizawa. Microstructure and superconducting properties of Dy-Ba-Cu-O bulk superconductors fabricated in different oxygen atmospheres. *Physica C* 2005; 426-431: pp.660-665.

[9] R.M. Spriggs. Expression for effect of porosity on elastic modulus of polycrystalline refractory materials, particularly aluminum oxide. *J Am Ceram Soc* 1961; 44: pp.628-629.

[10] W. Duckworth. Discussion of Ryshkewitch paper by Winston Duckworth. *J Am Ceram Soc* 1953; 36: p.68.

[11] A. Murakami, K. Otaka, T. Miura, A. Iwamoto. Effects of Pt content on mechanical properties of Dy123 bulks. Submitted to *Phy. Proc.*.